Influence of drift oscillations on the ionic thermal conductivity of a plasma

A. S. Bakaĭ, V. S. Voĭtsenya, A. Yu. Voloshko, S. I. Solodovchenko, and A. F. Shtan'

Physicotechnical Institute, Ukrainian Academy of Sciences
(Submitted 25 October 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **28**, No. 11, 682–685 (5 December 1978)

It is shown that drift oscillations cause an increased transport of fast ions, which can lead in the case of Maxwellian distribution function to anomalous ionic thermal conductivity.

PACS numbers: 52.35.Kt, 52.25.Fi, 52.55.Gb

1. The mechanisms that cause anomalous plasma energy transport in toroidal traps and are connected with plasma oscillations are presently widely discussed. Principal attention is being paid to anomalous transport via the electron channel. In this communication we call attention to the fact that plasma oscillations of the drift type can lead to an anomalous transport of fast ions.

It is known (e.g., Ref. 1), that drift waves in toroidal traps are built up by a

 0021-3640/78/230634-04$00.60

pressure gradient in the vicinity of the resonant surfaces. The radial width of the region of localization of the oscillations, $\Delta \sim \rho_i/\theta$ (θ is the shear and ρ_i is the ion Larmor radius), is determined by the fact that at this distance from the resonance surface the longitudinal (relative to the magnetic field) phase velocity of the drift wave becomes of the order of the thermal velocity of the ions, and the wave attenuates. If $v_{\rm ph}$ is the average longitudinal phase velocity of the wave and ϕ_0 is its amplitude, then ions for which

$$|v_{\parallel i} - v_{\rm ph}| < \sqrt{\frac{Ze\phi_0}{M_i}} \qquad (1)$$

($v_{\parallel i}$ is the ion velocity, M_i is its mass, and Z its charge) interact resonantly with the wave, and move along the magnetic force lines with average phase velocity $\bar{v} \approx v_{\rm ph}$. At the same time they drift transversely, $v_\perp \approx c\nabla_\perp \phi/B$, in the field of the wave and the transverse stream lines are close to the equipotentials. Thus, the drift wave generates mobile convective cells for the resonant ions.

The convective transport of these ions can take place over characteristic distances l_k much larger than Δ–in the presence of correlation between the field and the spatial ordering of the convective cells during the nonlinear stage of the development of the drift instability. In this case the transport coefficient is given by the expression[2] $D_\perp \approx l_k c \nabla\phi_0/B$.

For a Maxwellian distribution, the number of ions at resonance with the drift wave is exponentially small ($v_{\rm ph} \gg v_{Ti}$). However, in the case of neutral injection or HF heating, the fraction of the fast ions subject to the influence of the drift waves increases, and this leads to additional losses of energy from the plasma.

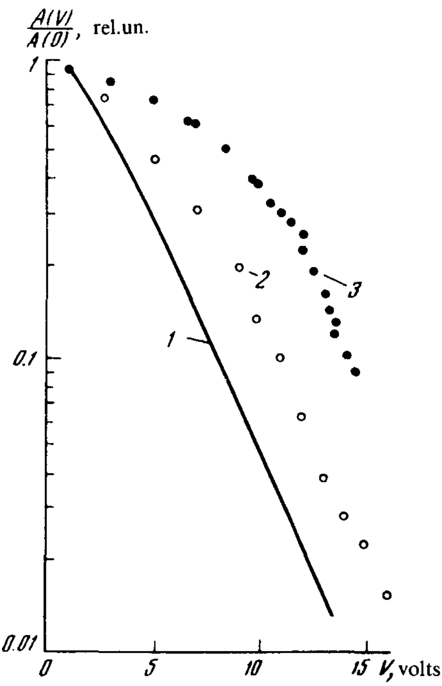

FIG. 1. Current-voltage characteristic of the probe.

The described mechanism of fast-ion transport is observed in the "Saturn" stellarator in an argon microwave-discharge plasma ($n_e \approx 10^{11}$ cm^{-3}, $n_0 < 10^{12}$ cm^{-3}, $T_e \approx 6$ eV, $T_i \approx 0.3$ eV). Under these conditions drift oscillations with frequency ~ 4 kHz and with level $\langle \tilde{n}^2 \rangle^{1/2}/\bar{n} \gtrsim 20\%$ were observed on the density gradient.[3]

The ion energy distribution was measured with the aid of a special probe.[4] Fig. 1 shows its current-voltage characteristic (curve 1) calculated for a Maxwellian distribution; it shows also the characteristics obtained at radii 3 and 6 cm (curves 2 and 3, respectively). Figure 2 shows the radial dependence of the relative flux of ions with

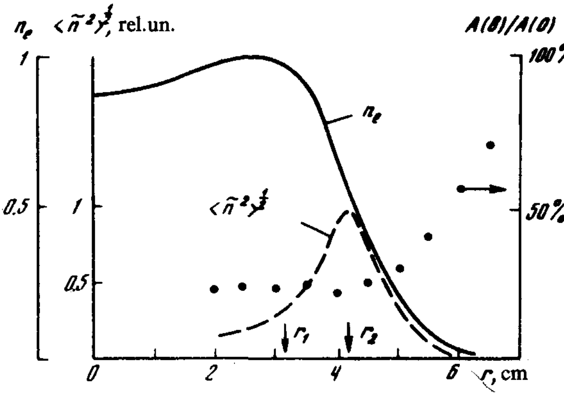

FIG. 2. Radial distributions: solid—of plasma density, dashed—of density fluctuations, ●—of the relative flux of ions with energy ⩾8 eV.

energies $\gtrsim 8$ eV (dark circles). The data in both figures attest to a continuous increase of the fraction of the fast ions ($v_i \gg v_{Ti}$) with increasing radius.

It was also noted that displacement of the probe to the region with the maximum level of the drift oscillations was accompanied by substantial change of the time behavior of the ion current to the collector, Fig. 3. In the internal region of the containment volume, $r < r_1$ (see Fig. 2), slight fluctuations are observed, Fig. 3a, and reflect the low level of the oscillations of the plasma density at this location. In the density-gradient region, $r > r_1$, the modulation of the ion current increases sharply, reaching $\sim 100\%$. For $r_1 < r < r_2$ it corresponds to "dips", Figs. 3b and 3c ($r_b < r_c$), while in the external regions of the plasma, $r > r_2$, it corresponds to "spikes," Fig. 3d. In all cases the modulation frequency is determined by the frequency of the drift oscillations, as shown by a comparison of the time behavior of the current of the "hot" ions (Figs. 3a–3d) and of the signal of the ion saturation current of the Langmuir probe (Fig. 3e).

3. The foregoing experimental results correspond, in our opinion, to the mechanism described in Sec. 1 for ion transport by a drift wave. An estimate of the radial displacement of the ion in the field of the wave during the period of the oscillations yields $l_r \gtrsim 1$ cm, which is comparable with the dimension of the inhomogeneity of the plasma $l_n = [(1/n)(dn/dr)]^{-1} \approx 1.5$ cm. Thus, convective transport of resonant ions in a drift wave takes place under conditions of the present experiments.

This mechanism of energy loss through the ion channel may become substantial if "tails" of hot ions are produced as a result of additional plasma heating. In fact, in the TFR tokamak, an increase of the anomaly of the ion thermal conductivity under neutral injection was accompanied by an enhancement of the drift oscillations.[5,6] Unfortunately, these data and the data obtained with other installations,[7,8] are not suffi-

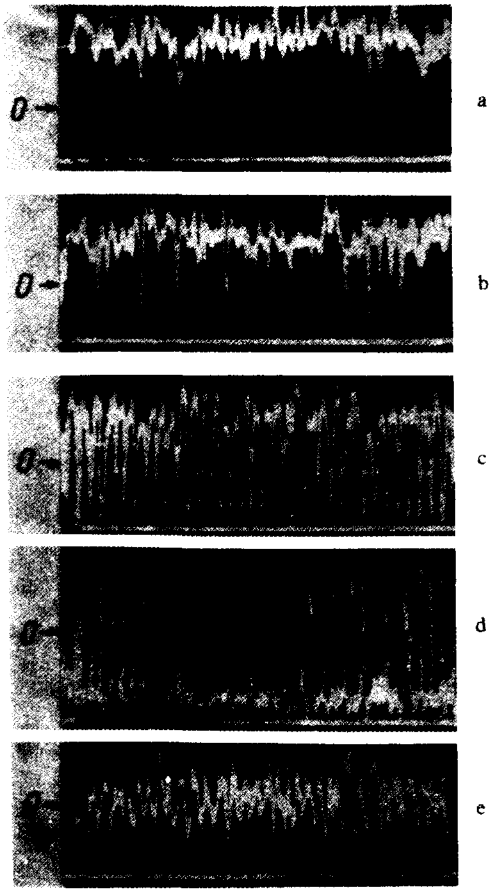

FIG. 3. Oscillograms: a—d) of ion current to the collector, e) of saturation ion current of the Langmuir probe.

ciently complete and do not permit an estimate of the contribution of this transport mechanism of the energy lost via the ion channel.

[1]B.B. Kadomtsev and O.P. Pogutse, in: Voprosy teorii plazmy (Problems of Plasma Theory), Vol. 5, Moscow, 1976.
[2]A.S. Bakaĭ, IAEA, Innsbruck, 1978, Paper CN-37-X-4-2.
[3]V.S. Vojtsenya *et al.*, Nucl. Fusion **17**, 651 (1977).
[4]R.W. Motley and T. Kawabe, Phys. Fluids **14**, 1019 (1971).
[5]Equipe TFR, Nucl. Fusion **18**, 1271 (1978).
[6]Equipe TFR, IAEA, Berchtesgaden **1**, 35 (1976).
[7]E. Mazzuckato, Phys. Fluids **21**, 1063 (1978).
[8]D. Grove *et al.*, IAEA, Berchtesgaden **1**, 21 (1976).